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Instruction Manual

Model 6150

MEMS In-Place Inclinator

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1. INTRODUCTION

The Geokon Model 6150 MEMS In-Place Inclinometer system is designed for long-term monitoring of deformations in structures such as dams, embankments, foundation walls and the like. The basic principle is the utilization of tilt sensors to make accurate measurement of inclination, over segments, in boreholes drilled into the structure being studied. The continuous nature of the instrument allows for very precise measurement of changes in the borehole profile to be measured. The instrument is installed in standard grooved inclinometer casing. See Figure 1.

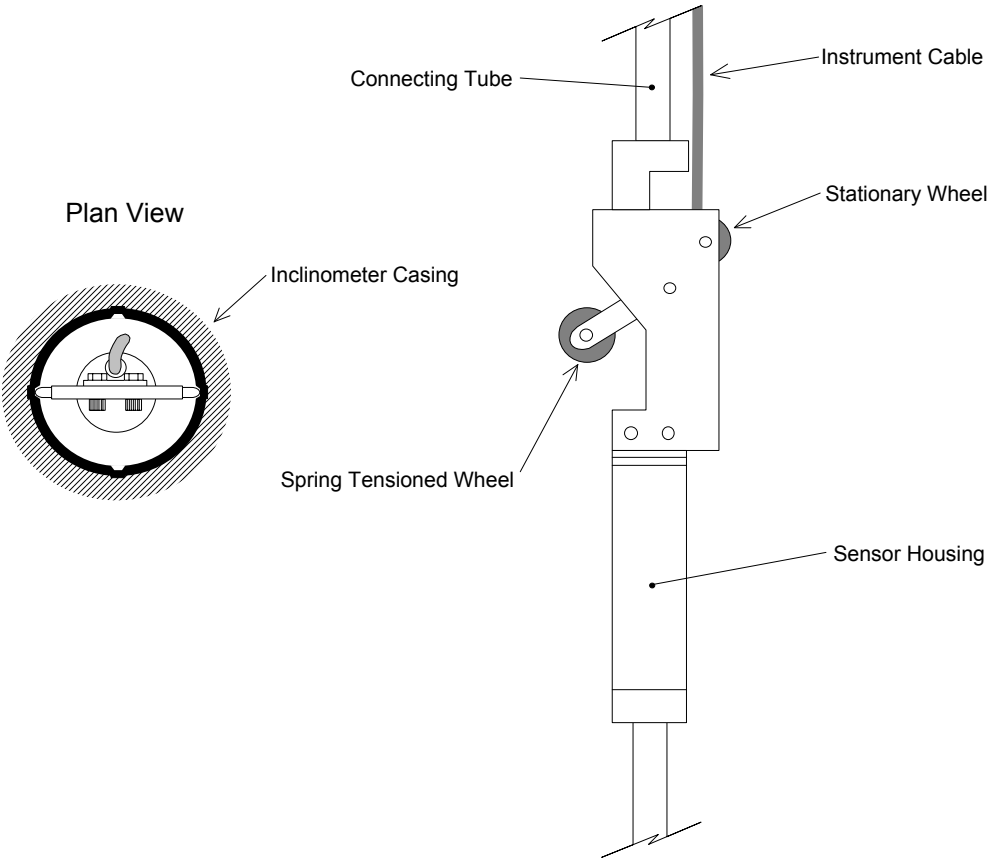


Figure 1 - Model 6150 MEMS Tilt Sensor Assembly

1.1. Tilt Sensor Construction

The sensor comprises one or two micro-electrical-mechanical-systems, (MEMS), sensors mounted inside a sealed housing. The Housing has a mounting bracket on its upper end for connecting the sensor to a wheel assembly, which centralizes the sensors and allow the assembly to be lowered into the casing. A lug on the lower end connects to a universal coupling, which allows unimpeded relative movement between the spacing rods, and a swivel joint which accommodates any spiraling of the casing, and prevents the wheel assemblies from running out of the casing grooves. Stainless steel tubing is used to connect and space apart the transducer and wheel assemblies, and the whole string is normally supported from the top of the casing. Biaxial systems use two transducers mounted at 90° to each other. Each housing contains a thermistor for reading temperatures.

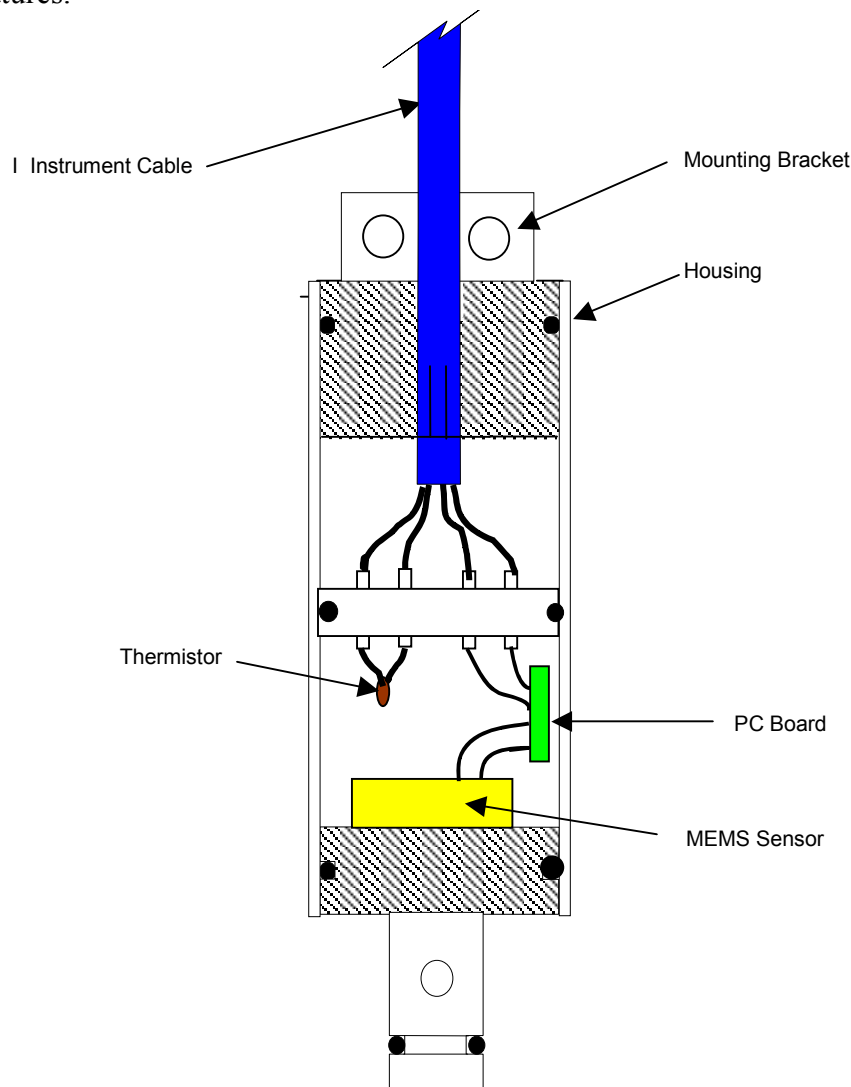


Figure 2 - Model 6150 Uniaxial Tilt Sensor

Note. The use of a safety cable, attached to the bottom wheel assembly, is strongly recommended. Not only can it be used to retrieve the assembly in the event that one of the joints breaks loose, but it is also very useful in lowering the assembly into the casing.

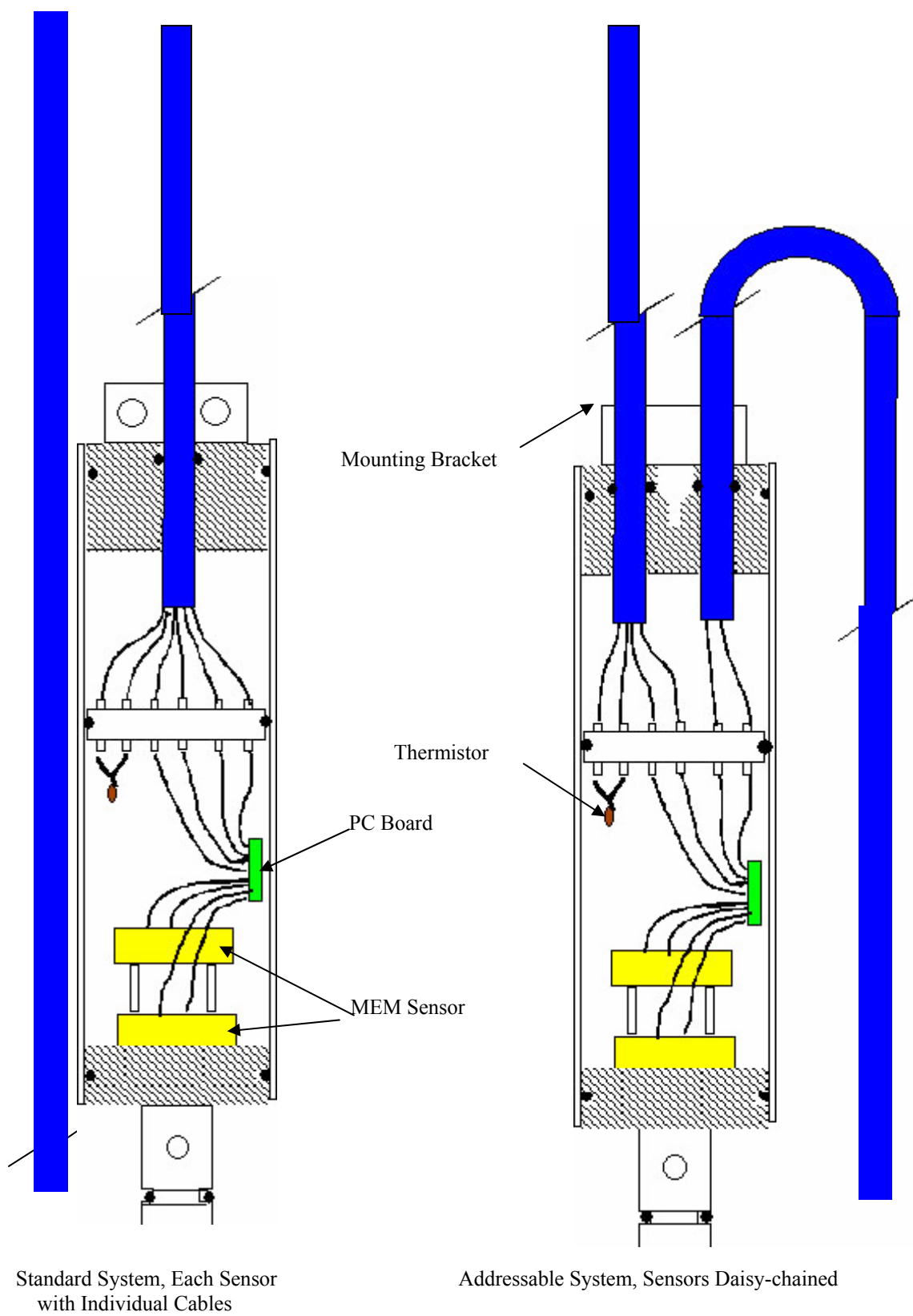


Figure 3 - Model 6150 Biaxial Tilt Sensor

2. INSTALLATION

2.1. Preliminary Tests

Standard system

Prior to installation, the sensors need to be checked for proper operation. Each tilt sensor is supplied with a calibration sheet, which shows the relationship between output voltage and inclination. The tilt sensor electrical leads (Red and Black leads are Power, Black, (B) and White, (A), are the Outputs), are connected to a Datalogger or RB-500 readout box (see section 3) and the current reading compared to the calibration readings. Carefully hold the sensor in an approximately vertical position and observe the reading. The sensor must be held in a steady position. The readings should be close to the factory vertical reading. The temperature indicated by the thermistor, and readout on the green and white wires using an ohmmeter, should be close to ambient.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the Green and Black pair should be approximately 3000 ohms at 25° (see Table B-1), and between any conductor and the shield or the case should exceed 2 megohm.

2.2. Model 6150 Assembly and Installation

- 1. Connect the safety cable to the bottom wheel assembly.** (See Figure 5) This is strongly recommended. Not only can it be used to retrieve the assembly in the event that one of the joints breaks loose, but it is also very useful in lowering the assembly into the casing. The alternative is to hold the tube sections with vice-grips at the top of the casing.

The bottom wheel assembly is labeled and has no universal joint, just the swivel. The safety cable has a loop at its bottom end which fits over the long bolt used to hold the bottom wheel assembly to the first tube section. This is shown in Figure 5. The cable eyebolt is trapped between two nuts.

- 2. Connect the first length of gage tubing to the wheel assembly.** The lengths of tubing making up the IPI string are shown in a table supplied separately along with the calibration sheets. Where the inter-anchor spacing is large, two tubes are joined together by a special union. Use the 10-32 screws and nuts, and a thread locking cement to make this joint.

Note: Tubing joints are purposely made to close tolerances. If the screws will not pass through the joint, it must be reamed with the drill provided (.193").

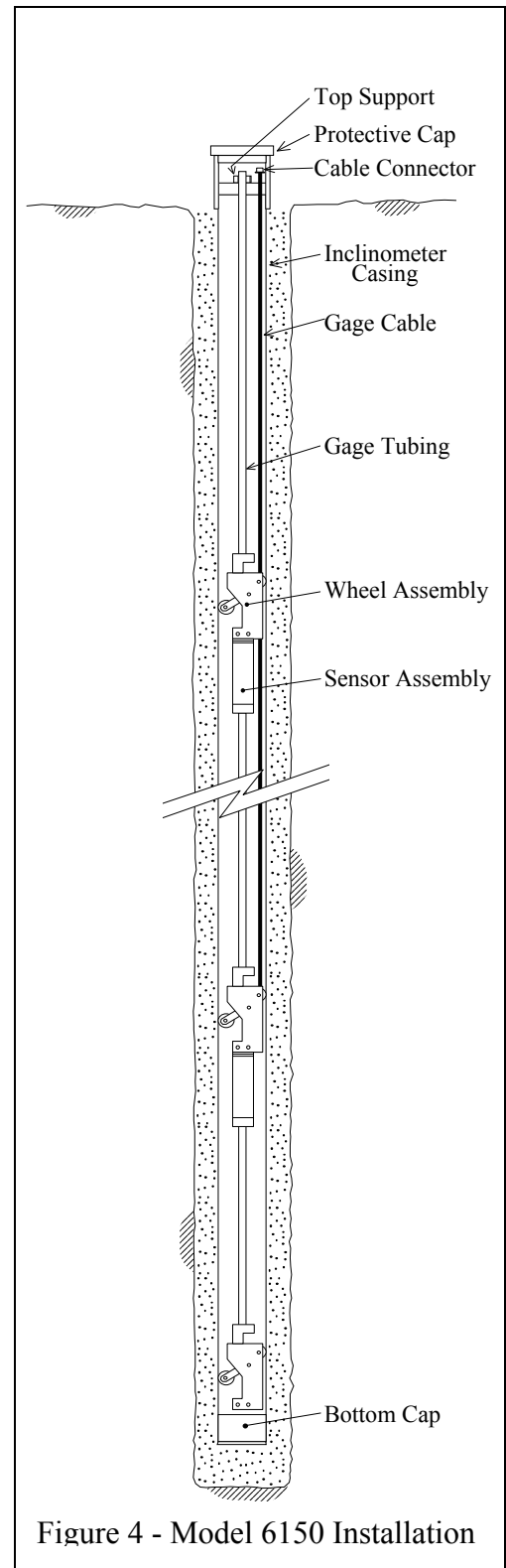


Figure 4 - Model 6150 Installation

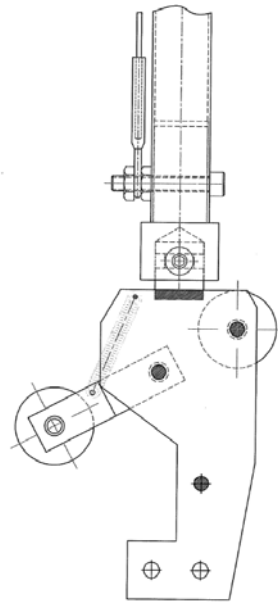


Figure 5 Bottom Wheel Assembly

3 The next step is to attach the sensor assembly.

The uniaxial sensor is delivered unattached to its wheel assembly and should be attached using the two 10-32 nuts and cap screws supplied. The tongue of the sensor fits inside the slot of the wheel assembly with the orientation set such that the A+ direction marked on the sensor is aligned on the same side as the fixed wheel on the wheel assembly. Tilts in the positive direction yield increasing readings in digits.

The sensor and wheel assembly is now attached to the first tube section using a single long 10-32 capscrew. (Use Loctite222 on all threads)

With a biaxial system a second MEMS sensor is included in the housing and is attached with its positive direction 90° clockwise from the upper sensor (looking downwards in plan). This is the B+ direction. See Figure 6.

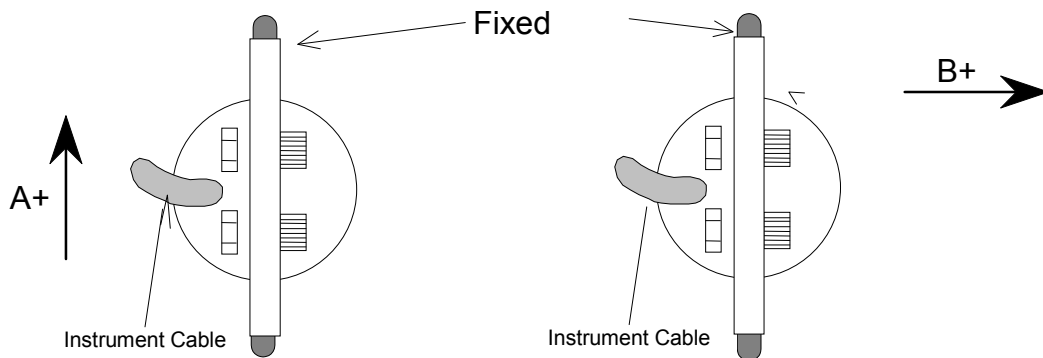


Figure 6 - Biaxial Sensor Orientation

4. Assembling the IPI string

This gage assembly is now lowered into the borehole, using the safety cable, with the upper assembly fixed-wheel aligned in the so-called A+ direction. It is customary (and recommended) to point the A+ direction in the same direction as the anticipated movement, i.e, towards the excavation being monitored or down-slope in the case of slope stability applications. Be sure that the lower wheel assembly and swivel are also aligned this way.

While holding the assembly at the top of the casing, the next segment with sensors, wheels and swivel are attached and lowered in the same orientation. The system can become quite heavy and a clamp of some sort (vice grips) should be used to hold the rods in place while being assembled. The use of a winch to hold the safety cable can be of help. Note that the longer cables are on reels to facilitate handling. Something like two little saw horses (or even folding chairs) with a broom stick across them to act as an axle will allow the cable to spool off as needed, avoid entanglements and provide a holding point for extra cable.

The cables from the lower sensors should be taped or tie-wrapped to the assembly at intervals to prevent interference as the system is built up and lowered down the borehole.

Continue to add gage tubing, sensors and wheel assemblies until the last sensor has been installed. At this point, the top suspension must be attached to the upper wheel assembly (or the gage tube). The assembly is bolted to the wheel assembly (or tube) as before, and then lowered into position on the casing. It is important that the casing be relatively square to prevent any side interference in the upper sensor wheel assembly.

After the sensor string is lowered into position, the safety cable can be tied off around the top of the casing and the signal cables can be run to the readout location and terminated at a switch box or otherwise fixed. Readings can be taken immediately after installation, but it is recommended that the system be allowed to stabilize for a few hours before recording zero conditions.

2.3 Connection to Switch – Boxes or Datalogger –Standard System

For manual readout using a RB-500 readout box, cables from the individual sensors are connected to a switch-box using the wiring code shown in Appendix A. If a Datalogger is used the cables are connected directly to the Multiplexer using the same wiring code.

3. TAKING READINGS

3.1 Dataloggers

In most cases the 6150 MEMS In-place Inclinometer will be monitored continuously and automatically using a Datalogger. Connections to the Geokon Model 8021 Micro-1000 Datalogger, which uses a Campbell Scientific CR1000 MCU, are shown in Appendix C Page 15. Dataloggers are also used to read Addressable IPIs which use a single cable to access all the sensors as described in Appendix D, page 16.

3.2 RB-500 Readout Box

The Readout Box incorporates a 12 volt, 1.2 Ahr Lead acid battery, a 4½ digit liquid crystal display (LCD), a power on/off switch, an A/B selector switch, a battery charger circuit, an AC adaptor connector, and an Input Junction Box Assembly.

The RB-500 instrument supplies +12V power to the MEMS sensor and displays the output in Volts which is proportional to the sine of the angle of inclination.

Note that the RB500 does not read temperatures. To read temperature with uniaxial sensors only, connect a digital ohmmeter to the Green and Green's Black leads and read the resistance in ohms.

Use the table in Appendix B to find the temperature.

3.3 Measuring Temperature

Although the temperature dependence of the MEMS tilt meter is close to zero, and usually does not require compensation, it sometimes happens that temperature effects can cause real changes of tilt; therefore each MEMS tilt sensor is equipped with a thermistor for reading temperature. This enables temperature-induced changes in tilt to be distinguished from tilts due to other sources. The thermistor gives a varying resistance output as the temperature changes. Check the instrument wiring codes for the thermistor connections.

1. The RB-500 cannot read temperatures - Connect a digital Ohmmeter to the two thermistor leads coming from the tilt sensor. (See appendix C for wiring code).
2. Look up the temperature for the measured resistance in Table B-1. Alternately the temperature could be calculated using Equation B-1. The effect of cable resistance is usually insignificant but for long cables it may be necessary to take into account the cable resistance (16 ohms/1000ft.)

The above remarks apply mainly to structures exposed to sunlight: in these situations it is not uncommon for the structure to expand and contract differentially during to course of the day. For land-slide applications where the MEMS sensors are buried in the ground, temperature variations are very small or non-existent and ground movements are unaffected by temperatures. In these situations it is not necessary to measure temperatures.

4. DATA REDUCTION

4.1. Tilt Calculation

The output of the MEMS Sensor is proportional to the sine of the angle of inclination from the vertical. For the +/- 15 degree sensor the FS output is approximately 4 volts. The relationship between the readings, **R**, displayed on channels A and B on the RB-520 readout box, and the angle of inclination, **θ**, is given by the equation:

$$\theta = \text{Sin}^{-1}(\text{RG}) \quad \text{or} \quad \text{Sin}\theta = \text{RG}$$

Equation 1 Inclination versus voltage.

Where **R** is the reading in on the RB-500 readout box and **G** is the Gage Factor ($\text{sin}\theta/\text{volt}$) shown on the calibration sheet. Note that the small voltage reading at zero inclination can be ignored since it is only the tilting, i.e. change of inclination that is of interest. Note also that for small angles $\text{sin}\theta = \theta$ radians.

So the amount of tilt, in degrees, is given by the equation

$$\text{Tilt} = \text{Sin}^{-1} (\text{R}_1 - \text{R}_0)\text{G degrees}$$

Equation 2 Tilt degrees versus voltage.

Positive values are tilts in the direction of the arrows A+ and B+

4.2. Temperature Correction

The Model 6150 MEMS Tiltmeter has very small temperature sensitivity equal to +1 arc second per degree centigrade rise. The tilt corrected for temperature is:

$$\text{Tilt} = \text{Sin}^{-1} (\text{R}_{1\text{corr}} - \text{R}_0)\text{G degrees}$$

Where $\text{R}_{1\text{corr}} = \text{R}_1 - 0.0003 (\text{T}_1 - \text{T}_0)$

Equation 3 Tilt versus voltage corrected for Temperature.

Normally, temperature corrections are not required. An important point to note is that sudden changes in temperature will cause both the structure and the Tiltmeter to undergo transitory physical changes, which will show up in the readings. The gage temperature should always be recorded, and efforts should be made to obtain readings when the instrument and structure are at thermal equilibrium. The best time for this tends to be in the late evening or early morning hours.

4.3. Deflection Calculation

The lateral offset, D , of the top of any segment relative to the vertical line running through the bottom of the segment is equal to $L\sin\theta$, where L is the length of the segment, between pivot points, and θ is the inclination of the segment to the vertical.

The length L_1, L_2, L_3, \dots etc., can be calculated by adding **336mm**, (both uniaxial and biaxial systems) to the individual lengths of tubing. This will give the correct distance between pivot points.

The profile of the borehole is constructed by using the cumulative sum of these lateral offsets starting with the bottom segment, L_1 . For instance, referring to figure 5, the total lateral offset of the top of the upper segment, (which is usually at the surface), from the vertical line drawn through the bottom of the lower segment, (located at the bottom of the borehole), is

$$D_5 = L_1\sin\theta_1 + L_2\sin\theta_2 + L_3\sin\theta_3 + L_4\sin\theta_4 + L_5\sin\theta_5$$

Equation 4 - Offset Calculation

Therefore, ignoring temperature corrections, and reading with the RB500 readout box

$$D_5 = G_1L_1R_1 + G_2L_2R_2 + G_3L_3R_3 + G_4L_4R_4 + G_5L_5R_5$$

And the deflection, ΔD , i.e. the change in offset is

$$\Delta D_n = \sum_1^n G_n L_n \Delta R_n$$

Equation 5 - Deflection Calculation

Where $\Delta R_1 = (R_1 - R_0)$ i.e. the present RB-500 reading on Tiltmeter 1 minus the initial reading on Tiltmeter 1; and $\Delta R_2 = (R_2 - R_0)$ i.e. the present reading on Tiltmeter 2 minus the initial reading on Tiltmeter 2; and similarly for all the other Tiltmeters.

Although the system is designed for use in continuous segments with pivots, the sensors can be installed without interconnecting tubing in standard, round tubing or pipe using special friction anchors. In those systems, the assumption is made that the measured deflection occurs over the segment length, the mid point of which is at the sensor location, and that L is the distance between adjacent midpoints.

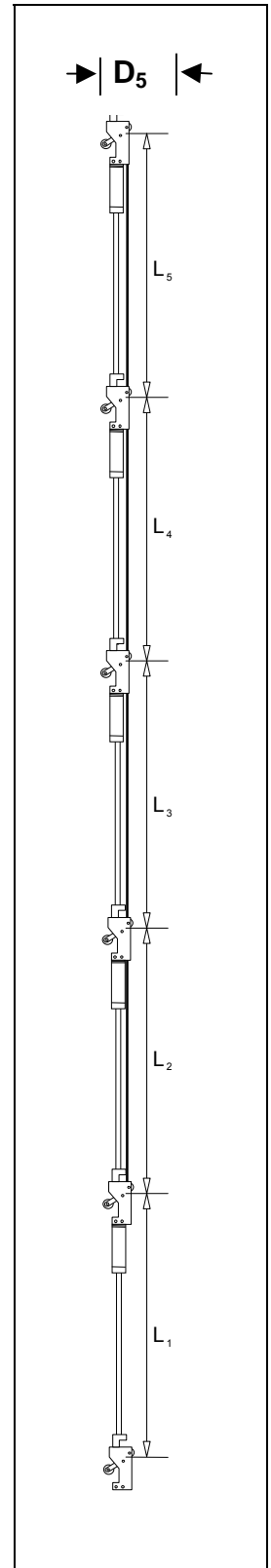


Figure 7 – Deflection Intervals



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MEMS Tilt Sensor Calibration

Model Number: MEMS Tilt SensorCalibration Date: February 06, 2008Serial Number: Sensor A 08-542Temperature: 25.5 °C

Technician:

Inclination (degrees)	Inclination (sin θ)	* Reading 1st Cycle (Volts)	* Reading 2nd Cycle (Volts)	* Average Reading (Volts)	Error in Calculated θ (%FS)	Calculated sin θ (%FS)
10.00	0.1737	2.7616	2.7590	2.7603	-0.05	0.02
8.002	0.1392	2.2190	2.2165	2.2178	0.01	0.00
6.000	0.1045	1.6743	1.6727	1.6735	0.05	0.00
4.002	0.0698	1.1281	1.1280	1.1281	0.05	0.00
2.002	0.0349	0.5803	0.5802	0.5802	0.03	-0.01
0.000	0.0000	0.0322	0.0320	0.0321	0.00	0.00
-2.002	-0.0349	-0.5155	-0.5157	-0.5156	-0.02	0.02
-4.002	-0.0698	-1.0625	-1.0632	-1.0629	-0.03	0.02
-6.000	-0.1045	-1.6081	-1.6089	-1.6085	-0.03	0.02
-8.002	-0.1392	-2.1524	-2.1538	-2.1531	0.00	0.02
-10.00	-0.1737	-2.6947	-2.6958	-2.6953	0.07	0.00

6150 and 6155 In-Place Inclinomater Gage Factor (G): 0.06368 (sin θ / Volt)

Temperature Correction Factor -0.0003 (T₁-T₀) Volts / °C

Deflection = GL(R₁-R₀) mm (inches)

6160 Tiltmeter Gage Factor (G): 3.6617 (degrees/ Volt)

Temperature Correction Factor -0.0003 (T₁-T₀) Volts / °C

Calculated Tilt = G(R₁ - R₀) degrees

Wiring Code: See manual for further information

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST,
in compliance with ANSI Z540-1.

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Figure 8 Sample Model 6150 MEMS Calibration Sheet

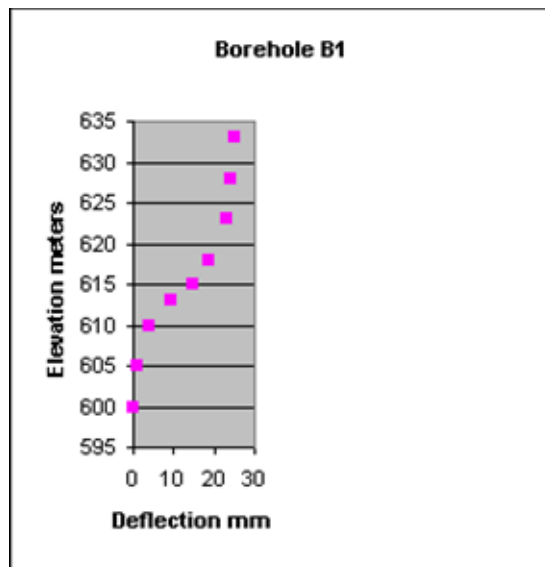
4.5 Sample Calculation

	MEMS		Borehole#1					
	DEFLECTION							
	CALCULATION							
SENSOR		L	Depth	Elevation	G	R0	T0	
		meters	meters	meters	Degrees/V	Volts	° C	

Surface			0	633			
1	5	5	628	0.06271	0.582	20	
2	5	10	623	0.06303	0.5632	18	
3	5	15	618	0.06221	0.5495	18	
4	3	18	615	0.06295	0.532	17	
5	2	20	613	0.06284	0.5144	17	
6	3	23	610	0.06291	0.4883	17	
7	5	28	605	0.06273	0.4321	17	
8	5	33	600	0.06289	0.3962	17	

		R1	T1	R1 _{corr}	R1 _{corr} -R0	GL(R1-R0)	Acc Defl	
		Volts	° C	Volts	Volts	mm	mm	

Surface							24.23
1	0.5802	10	0.5832	0.0012	0.38	23.85	
2	0.5644	12	0.5662	0.003	0.95	22.90	
3	0.5632	17	0.5635	0.0140	4.35	18.55	
4	0.5514	17	0.5514	0.0194	3.66	14.89	
5	0.5602	17	0.5602	0.0458	5.76	9.13	
6	0.5169	17	0.5169	0.0286	5.40	3.74	
7	0.4404	17	0.4404	0.0083	2.60	1.13	
8	0.3998	17	0.3998	0.0036	1.13	0	



4.4. Environmental Factors

Since the purpose of the inclinometer installation is to monitor site conditions, factors that may affect these conditions should be observed and recorded. Seemingly minor effects may have real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to: blasting, rainfall, tidal or reservoir levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

5. TROUBLESHOOTING

Maintenance and troubleshooting of the vibrating wire tilt sensors used in the Model 6150 Inclinometer are confined to periodic checks of cable connections. The sensors are sealed and there are no user-serviceable parts.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Tilt Sensor Readings are Unstable

- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or Datalogger.
- ✓ Does the readout work with another tilt sensor? If not, the readout may have a low battery or be malfunctioning.

Symptom: Tilt Sensor Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. The nominal resistance of the thermistor is 3000 ohms at 25 degrees C. If the approximate temperature is known, the resistance of the thermistor leads can be estimated and used as a cable check. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately $16\Omega/1000'$ or $52\Omega/km$, multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low ($<20\Omega$) a short in the cable is likely.
- ✓ Does the readout or Datalogger work with another tilt sensor? If not, the readout or Datalogger may be malfunctioning.

Symptom: Thermistor resistance is too high.

- ✓ Is there an open circuit? Check all connections, terminals and plugs.

Symptom: Thermistor resistance is too low.

- ✓ Is there a short? Check all connections, terminals and plugs.
-]✓ Water may have penetrated the interior of the tilt sensor. There is no remedial action.

APPENDIX A - SPECIFICATIONS

A.1. MEMS Tilt Sensor

Model:	6150
Range	$\pm 15^\circ$
Resolution: ¹	+/-2 arc seconds, (+/- 0.01mm/m)
Accuracy ²	+/-3 arc seconds
Linearity: ³	+/- 0.07% FS
Cross axis sensitivity	4%
Thermal Zero Shift:	0.0003 volt/°C rise
Operating Temperature	-20 to +70° C -4 to 158° F
Power Requirements:	6150-1 (Uniaxial): +12V (nom) @ 30mA 6150-2 (Biaxial): +12V (nom) @ 45mA
Sensor Output:	+/-4 Volts @ FS
Frequency Response:	-3db @ 8-28 Hz
Shock Resistance	2,000g
Thermistor Resistance:	3000Ω at 25°C
Sensor Housing Dia:	32 mm, (1.250").
Length:	187 mm,(7.375").
Weight:	0.7 kg. (1.5 lbs.).
Materials:	304 Stainless Steel
Electrical Cable:	3 twisted pair (6 conductor) 24 AWG Foil shield, Polyurethane jacket, nominal OD = 6.3 mm Or 6 twisted pair (12 conductor) 24 AWG Foil shield, Polyurethane jacket, nominal OD = 7.9 mm

Table A-1 Model 6150 MEMS Tilt Sensor Specifications

Notes:

¹ For best results requires a 4 ½ digit digital voltmeter.

Averaging will yield resolution on the order of 2 arc seconds

² Based upon the use of a second order polynomial

³ The output of the MEMS sensor is proportional to the sine of the angle of tilt

A.2. Thermistor (see Appendix B also)

Range: -80 to +150° C

Accuracy: $\pm 0.5^\circ$ C

APPENDIX B - THERMISTOR TEMPERATURE DERIVATION**Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3****Resistance to Temperature Equation:**

$$T = \frac{1}{A + B(\ln R) + C(\ln R)^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

Where; T = Temperature in °C.

LnR = Natural Log of Thermistor Resistance

A = 1.4051×10^{-3} (coefficients calculated over the -50 to +150° C. span)B = 2.369×10^{-4} C = 1.019×10^{-7}

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	3000	25	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Table B-1 Thermistor Resistance versus Temperature

APPENDIX C WIRING CODE

03-250V0 cable	Connector Pin Designation	Uniaxial MEMS with Thermistor	Connector Pin Designation	Biaxial MEMS without Thermistor
Red	A	12VDC	A	12VDC
Red's Black	B	Ground	B	Ground
White	C	A Out Diff +	C	A Out Diff +
White's Black	D	A Out Diff -	D	A Out Diff -
Bare	E	Shield	E	Shield
Green	J	Thermistor	F	B Out Diff +
Green's Black	K	Thermistor	G	B Out Diff -

Table C-1 Cable 03-250V0 Wiring

06-312V0 Cable	Connector Pin Designation	Biaxial MEMS with Thermistor
Red	A	12VDC
Red's Black	B	Ground
White	C	A Out Diff +
White's Black	D	A Out Diff -
Bare	E	Shield
Green	F	B Out Diff +
Green's Black	G	B Out Diff -
Blue	J	Thermistor
Blue's Black	K	Thermistor

Table C-2 Cable 06-312V0 Wiring

APPENDIX D 6150 STANDARD ADDRESSABLE SYSTEMS

Description:

The standard 6150 addressable system incorporates a Distributed Multiplexer Circuit Board that allows multiple MEMS type Inclinometers, uniaxial or biaxial, to be connected as “drops” off of a single bus.

The Inclinometer “string” is addressed via ENABLE and CLOCK signals in the same manner as the Geokon Model 8032-16 Channel Multiplexer.

The addressable Inclinometer string is “enabled” by raising the appropriate Datalogger Control Port to 5V. After the string has been enabled, a delay of 125 mS is required before executing the 1st of the two clock pulses required to activate the 1st channel. Once the channel is selected, a delay of 100 mS is required for the sensor to warm-up. The sensor’s A-axis is read 100 times and then the average of these readings is stored. The sensors B-axis is then read. Finally, the sensor’s thermistor is read through a bridge completion circuit and the temperature is calculated using a polynomial formula. Examples of CRBASIC programming can be found in Appendix F.

Wiring:

06-312V0 Cable Color	Connector Pin Designation	Addressable MEMS System (Logic Level Style)
Yellow	A	A-axis Output Differential +
Yellow’s Black	B	A-axis Output Differential -
Brown	C	B-axis Output Differential +
Brown’s Black	D	B-axis Output Differential -
Red	E	12VDC
Red’s Black	F	Ground
White	G	Reset
White’s Black	H	Ground
Green	J	Clock
Green’s Black	K	Ground
Blue	L	Thermistor*
Blue’s Black	M	Thermistor*
Bare	P	Shield

Table D-1 Addressable MEMS (Logic Level Style) Wiring

* 1K and 5K precision resistors are used to complete the thermistor bridge circuit:

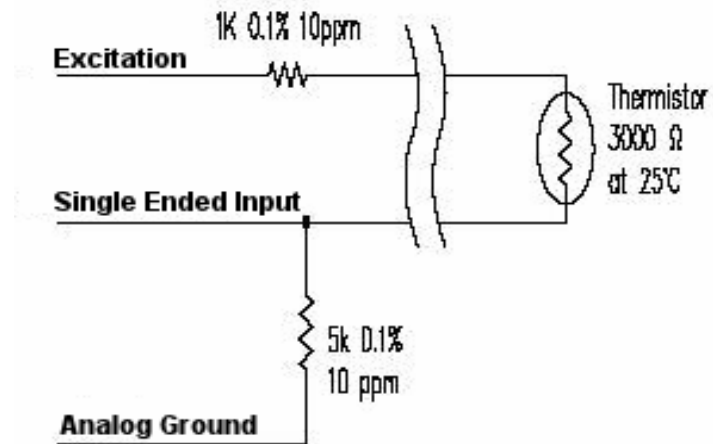


Figure D-1 Thermistor Bridge Circuit

Specifications for Addressable System (Logic Level Style) Circuit Board:

Board Dimensions:	4.5”(L) x 1.155”(W) x 0.4”(H)
Power Requirements:	+12V (+/- 3V) 110mA (max) when active 700uA (max) standby
Operating Temperature:	-20 to +70° C
Contact Resistance:	100 mΩ (typ)
Contact Breakdown Voltage:	1500 Vrms
Relay open/close time:	4mS (max)

APPENDIX E CRBASIC PROGRAMMING

Programming the MEMS Inclinometer with CRBASIC

Description:

CRBASIC is the programming Language used with Campbell Scientific CRBASIC Dataloggers. Campbell's Loggernet Software is typically used when programming in CRBASIC. The MEMS sensor should be read with the VoltDiff instruction and the output averaged 100x. No Thermistor in this example.

Sample Program:

'Declare Public Variables for Reading MEMS Sensor

```
Public MEMS_1
Public MEMS_2
Public MEMS_3
Public MEMS_Output 'Output of the MEMS Sensor
```

'Store MEMS Output every 2 minutes

```
DataTable (MEMS_EXAMPLE,1,-1)
Sample (1,MEMS_Output,IEEE4)
EndTable
```

```
BeginProg
```

'2 min scan interval

```
Scan (2,min,0,0)
```

'Read MEMS Sensor on Differential Channel 1 and average 100x Readings

```
Delay(0,100,mSec)
MEMS_3 = 0
For MEMS_1 = 1 To 100
VoltDiff (MEMS_2,1,mV5000,1,False,0,250,0.001,0)
MEMS_3 = MEMS_3 + MEMS_2
Next
MEMS_Output = MEMS_3 / 100
```

```
CallTable MEMS_EXAMPLE
NextScan
EndProg
```

Programming the Addressable MEMS Inclinometer with CRBASIC

Description:

CRBASIC is the programming Language used with Campbell Scientific CRBASIC Dataloggers. Campbell's Loggernet Software is typically used when programming in CRBASIC. The MEMS sensor should be read with the VoltDiff instruction and the output averaged 100x.

Sample Program:

The following sample program reads 6 addressable uniaxial MEMS Gages and Thermistors. The A-Axis is read on Differential Channel 1, the Thermistors are read with Single Ended Channel 5 and the bridge excited with VX1. The string is enabled with Control Port 1 and clocked with control port 8. A bridge completion circuit must be used to read Thermistors.

'Reads 1 uniaxial MEMS string with 6 Gages and 6 Thermistors

'Declare Public Variables for all gages and calculations

```
Public MEMS_1
Public MEMS_2
Public MEMS_3
Public THERM_1
Public THERM_2
Public THERM_3
Public Reading_IPI_1(6) 'IPI String Reading for 6 Gages
Public Reading_THERM_1(6) 'Thermistor Readings for 6 Gages
```

'Declare Constants for Thermistor Readings

'Coefficients for Steinhart-Hart equation

```
Const A = .0014051
Const B = .0002369
Const C = .0000001019
```

'Counter

```
Dim i
```

'Store MEMS outputs and Thermistors every Scan

```
DataTable (MEMS_IPI,1,-1)
```

```
Sample (6,Reading_IPI_1(),IEEE4)
Sample (6,Reading_THERM_1(),IEEE4)
```

```
EndTable
```

BeginProg

'30 second scan interval

Scan (30,sec,0,0)

'Enable String using C1

PortSet(1,1)

'Delay

Delay(0,125,MSEC)

'Counter to loop 6 times

For i = 1 To 6

'1st clock using C8 (there is two clock pulses required for each gage)

PortSet(8,1)

Delay(0,10,MSEC)

PortSet(8,0)

Delay(0,10,MSEC)

'Read the A-axis

'Reset the temporary storage location for the 100 average readings

MEMS_3 = 0

'Counter to take 100 readings

For MEMS_1 = 1 To 100

'Differential voltage measurement on Differential Channel 1

VoltDiff (MEMS_2,1,mV5000,1,False,0,1000,0.001,0)

'Take the average

'Sum the readings

MEMS_3 = MEMS_3 + MEMS_2

Next

'Calculate the Average reading value out of 100 readings

Reading_IPI_1(i) = MEMS_3 / 100

'Thermistor Reading

BrHalf(THERM_1,1,mV2500,5,VX1,1,2500,0,1000,250,2.5,0.0)

'Calculate the temperature

THERM_2 = THERM_1 / 5000

THERM_3 = (2.5 - (THERM_2*1000) - THERM_1)/THERM_2

Reading_THERM_1(i) = (1/(A+B*LN(THERM_3)+C*(LN(THERM_3))^3)-273.15)

'2nd clock using C8 to advance to next gage and thermistor

PortSet(8,1)

Delay(0,10,MSEC)

PortSet(8,0)

Delay(0,10,MSEC)

'Next channel counter

Next i

'Disable string

PortSet (1,0)

'Store Data for the IPI string

CallTable MEMS_IPI

NextScan

EndProg